

## NIST Large Fire Laboratory

George W. Mulholland and David Stroup

The purpose of the NIST Large Fire Laboratory (LFL) is to apply quantified measurements, real-time analysis, and large area diagnostics to validate models for fire phenomenon including fire dynamics, detection, and suppression. The LFL is also used for obtaining product yield data and HRR data for model input for fire models and for carrying out large scale tests requiring specialized instrumentation and data interpretation. An overview of the LFL development, recent experiments and planned enhancements will be described below.

### Capabilities of the Renovated Exhaust System

In 2000, the exhaust facility for our large scale facility was upgraded to remove smoke particulate using a baghouse and acid gases with a scrubber. In addition, the exhaust capacity of the facility was increased more than 20 fold to a flow of 42 m<sup>3</sup>/s. The increased flow allows fire experiments to be carried out with heat release rate (HRR) as large as 10 MW for the 9 m × 12 m hood. This is near the peak HRR for a small house. A 6 m × 6 m hood is available for fire tests as large as 3 MW. In addition there are two smaller hood assemblies with dimensions of 2.5 m × 2.5 m and 1.2 m × 1.2 m that in the future will allow smaller burns when connected to the exhaust system. The full suite of hoods/exhaust capabilities will allow fire experiments ranging in size from about 5 kW to transient peak HRRs as large as 15 MW. The total high bay floor space for enclosure assemblies is 9 m × 30 m. The height of the base of the 9 × 12 m hood is 6.4 m allowing fire tests for a two story structure.

### Quantitative HRR Calorimetry

The heat release rate (HRR) is the single most important quantity characterizing the hazard resulting from the burning of a given fuel package. It will determine the temperature within the enclosure, and the concentration of the combustion products including the smoke particulates and the toxic gases (CO and HCN) will be proportional to the HRR. A major focus of the LFL for the past two years has been the accurate measurement of HRR including a quantitative uncertainty assessment.

Our method is based on oxygen consumption calorimetry. The scientific basis of the method is that the HRR is proportional to the oxygen consumption together with the finding that for most materials found in buildings the heat of combustion per kg of oxygen consumed,  $H_c$ , is 13.1 MJ. The equation for the HRR is given by<sup>1</sup>:

$$\dot{Q} = (X^0(O_2) - X(O_2))H_c \rho(O_2) \dot{V}$$

where  $X(O_2)$  is the oxygen mole fraction,  $\rho(O_2)$  the density of oxygen, is the volumetric flow of ambient air into the combustion zone. There are a number of complications in performing quantitative measurements. First, the value of  $H_c$  is affected by incomplete products of combustion such as CO. Secondly, the exhaust flow is measured rather than the inlet ambient flow and the flow must be corrected to account for the changes in stoichiometry as oxygen is

consumed and CO, CO<sub>2</sub>, and H<sub>2</sub>O are produced. Thirdly, the uncertainty in the measurement increases for small fire sizes because of the small change in the oxygen concentration.

Our methodology for performing the measurements is to collect all the combustion products in the 6 m square hood, pass the flow through a flow straightener, measure the duct flow velocity at eight locations using bi-directional probes, and sample the smoke at multiple locations using a sampling probe cross. A high flow diaphragm pump rapidly directs the smoke flow to the O<sub>2</sub>, CO<sub>2</sub>, and CO analyzers from the sampling location on the roof of the Laboratory through a heated line about 20 m to the instrumentation room on the first floor. The moisture is removed with a dry-ice trap before the gas enters the analyzers. There is approximately a 15 s delay from the time the smoke leaves the flame until the gas sample is detected by the gas analyzers and this delay time is compensated for in the data analysis. During the upcoming year a helium tracer gas method will be used for accurately characterizing the duct flow.

Three additional capabilities critical to enhancing the accuracy and usefulness of our heat release measurements are a calibration burner, a data acquisition/control system capable of providing nearly real-time output, and a natural gas heat of combustion "meter."

### Calibration Burner

The burner consists of 11 tubes in a 1.6 m × 1.2 m planar array with holes spaced approximately every 2.5 cm along the tubes. Valves control the fuel flow to various sections of the burner so that the flame dimensions will be similar to that of a buoyancy dominated diffusion flame as the flow is increased. The Fire Dynamics Simulation Code was used in designing the burner. The heat of combustion of the natural gas used by burner is measured by an accurate gas calorimeter. Other important design features are the use of industrial control devices for monitoring and controlling the flow rate and for shutting off the flow if the flame extinguishes. The flow monitoring device is calibrated at the NIST flow metering facility. The burner has been successfully tested over the heat release range from 50 kW to 6 MW.

### Data Acquisition System

A dual processor workstation computer with National Instruments<sup>1</sup> hardware has been assembled with a LabVIEW program designed to compensate for different measurement times to achieve near real-time analysis and display of processed data. In typical use, 1 second averages for 60 channels are scanned at 200 Hz during a one hour test. In addition, the system can be used to control the fuel flow to have step changes or quadratic time dependence to simulate the typical growth rate for fires. The controlled burner and the heat release apparatus has been used for assessing the repeatability of the HRR calorimeter for fire sizes of 50 kW, 700 kW, to 3 MW. The hood was operated at two exhaust flow rates and 3 repeat measurements were made for each condition. For the larger two HRRs, the measured value agreed with the calibration burner to within 2 % and the measurement repeatability was within 6 %. The variation in the smallest

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<sup>1</sup> Certain commercial equipment or materials are identified in this paper to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the national institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for the purpose.

HRR was over 20 % and found to be a result of drift in the output of the oxygen meter. Efforts are underway to correct for the background drift of the analyzer and to purchase a lower drift oxygen meter.

## **Recent Large Scale Tests**

The following major studies have been carried out in the LFL since its renovation: bed fires, smoke detector study, and sub-lethal toxicity measurements. These studies illustrate the range of capabilities in the LFL.

### **Bed Fires**

The objective of the bed fires, sponsored by the Sleep Products Safety Council, was to quantify the relation between the heat release rate from a burning bed and the distribution of heat flux to the space around it<sup>2</sup>. Such heat fluxes might ignite other objects, leading toward room flashover. The information was in turn used to infer the largest tolerable bed fire that would both preclude other item ignition and minimize casualties due to heat and toxic gas exposures. The LFL six meter hood provided a unique capability to measure a very diverse range of bed fires which varied 100 kW to 5 MW.

### **Smoke Detector Study**

In co-operation with the United States Fire Administration (USFA), other sponsors, and U.S. Consumer Product Safety Commission (CPSC), NIST coordinated the evaluation of current and emerging smoke alarm technology responses to common residential fire scenarios and nuisance alarm sources. The measurements were all carried out in a manufactured home contained within the LFL. Unique capabilities provided by NIST include the detailed characterization of the environment near the detector including the temperature, flow, gas concentrations, smoke particle concentration, particle size and optical density. The quality of the data was greatly enhanced by fully characterizing the response of the 150 gas and particle detectors used in the study with the unique Fire Emulator/Detector Evaluator developed at NIST.

### **Sub-lethal Effects Experiments**

This study funded by the Fire Protection Research Foundation of National Fire Protection Administration is focused on characterizing the yields of toxic gases and smoke particulate produced by both pre-flashover and post-flashover fires. The room contents included electric cables, sofa mockups, or bookcases with and without a sheet of PVC. The test required characterization of the environment at two sampling locations with sensors for temperature (bare and aspirated thermocouples), velocity (bi-directional probes). Standard gas analysis included CO, CO<sub>2</sub>, and O<sub>2</sub>. An innovative feature of the experiments was the use of multiple FTIRs monitor the concentration of additional gases, such as HCl, HBr, HCN, and acrolein. In addition, for the first time at NIST, smoke was sampled in the upper layer leaving the doorway during flashover conditions. The smoke sampling included a temperature controlled filter assembly and a quantitative method for removing smoke deposited on the walls of the sampling tube.

Measurements at upstream and downstream locations enable estimation of the loss of smoke components to the walls.

## **Future Capabilities**

We plan to develop the following challenging capabilities during the next year: soot volume fraction in the hot upper layer, heat transfer measurements to steel elements, to cable trays, and to the walls, and surface temperatures for metals, insulating materials, and cables.

There is also great interest in the application of large area imaging optical diagnostics to large scale fires. The current status of projects for measuring water spray and doorway flows are briefly described below.

### **Water Spray**

An advanced measurement method is under development, with the goal of providing simultaneous measurement of sprinkler spray drop size and velocity. The method illuminates a 0.5 m by 0.5 meter area of the spray field with laser pulses, and uses laser induced fluorescence to image the droplets. Velocity is determined by analysis of the distance between two-color droplet pairs, and droplet size is determined from the size of the droplet images. Droplet sizes over the range of approximately 200  $\mu\text{m}$  to 3000  $\mu\text{m}$  can be measured, with low levels of uncertainty. Droplet velocities are accurately measured over the range 0.5 m/s to 50 m/s.. Data has been collected and analyzed data for 27 different parameter sets for an axially-symmetric sprinkler. The long term plan is to characterize the droplet size and velocity in the LFL for a sprinkler interacting with a fire plume.

### **Particle Imaging Velocimetry**

Particle Image Velocimetry (PIV), a non-intrusive laser-based measurement technique, is being applied to measure two-dimensional fields of velocity vectors in the lower layer of a fire-induced doorway flow. The technique significantly improves upon the spatial and temporal resolution of traditional bi-directional probe measurements. Two-dimensional images of gas velocity vectors were recorded last year using the PIV technique for a 26cm x 26cm region along the axis of a surface opening for ambient conditions. The data included instantaneous velocity field, instantaneous vorticity field, and mean flow streamlines, respectively. This year The PIV system was upgraded to 3D so that all three components of the velocity vector can be measured in a single acquisition. A reduced scale buoyant He plume and enclosure were designed and fabricated. It is anticipated that measurements will be completed this fall and the measurement of doorway flows for a full scale experiment are planned for 2004.

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<sup>1</sup> Parker, W.J., "Calculations of the Heat Release by Oxygen Consumption for Various Applications," *J. Fire Sciences*, 2, 380-395 (1984).

<sup>2</sup> Ohlemiller, T.J. and Gann, R.G., "Estimating Reduced Fire Risk from an Improved Mattress Flammability Standard," NIST Technical Note 1446, 2002.

## **NIST Large Fire Facility**

**George Mulholland, Fire Metrology Group  
Leader**

**David Stroup, Facility Manager**

**5th meeting of the International Sub-panel for Fire  
Research  
January 24, 2001**

## **Purpose of Large Fire Laboratory**

**Apply quantified measurements, real-time  
analysis, and large area diagnostics diagnostics  
to validate models for fire phenomenon  
including fire dynamics, detection, and  
suppression.**

## **Large Fire Laboratory Exhaust Capabilities**

- **Scrubber for removal of acid gases and baghouse for removal of particulate**
- **Variable from 0 to 42 m<sup>3</sup>/s**
- **Two Fixed Exhaust Hoods**
  - 6 m x 6m, 3 MW
  - 9 m x 12 m, 6 MW
- **Three Connection Ports**
  - 0.2 m Diameter
  - 0.5 m Diameter
  - 0.5 m Diameter

Picture of facility

## **Current Capabilities, 1/02**

- **6 m x 6 m Hood, Heat Release Rate in real time**
- **Calibration burner up to 6 MW**
- **9 m x 12 m Hood – Exhaust Only**
- **4 m x 4 m x 2.4 m Burn Enclosure**
- **Data system developed with near real time analysis/presentation of results**

## **Current Projects**

- **CPSC funded Smoke Detector study in manufactured home**
- **Fire Research Foundation study of Sub-Lethal Toxicity including flashover conditions**
- **STRS funded effort to plan experiments designed to support WTC fire models and fire resistance performance prediction**
- **STRS project to quantify the uncertainty in heat release rate calorimeter measurements**

## **Quantify Uncertainty in Heat Release Rate Calorimeter**

- **Why important: Heat release rate is the single most important quantity for characterizing the hazard by a given fuel package.**
- **Approach:**
  - **Develop real-time data acquisition/analysis capability**
  - **Develop calibration burner**
  - **Quantify the uncertainty of the measurement quantities**

### Heat Release Equation

$$\dot{Q} = (X_{O_2}^0 - X_{O_2}) H_C \rho_{O_2} \dot{V}$$

Where  $H_C$  is often assumed to be 13.1 kJ/kg and the duct flow,  $\dot{V}$ , is taken to be equal to the ambient flow.

#### Complications:

- $H_C$  is affected by CO production.
- $\dot{V}$  is affected by the change in stoichiometry as oxygen is consumed and CO, CO<sub>2</sub>, and H<sub>2</sub>O are produced.

### Illustration of Measurement System

Show sampling location, bi-direction probes and TC's, sampling line, trap, gas analyzers, "He flow system".

### **Data Acquisition/Analysis/Control Challenges**

- **Assembled dual processor workstation computer, National Instruments hardware**
- **Currently 192 analog input channels, 16 digital I/O channels**
- **Developed LabVIEW program for compensating for different measurement times to achieve near real-time analysis and display of processed data**
- **Typical use: 1 second averages for 60 channels scanned at 200 Hz during 1 hour test**
- **Capable of controlling/measuring calibration burner fuel flow rate**

### **Calibration Burner/Flow Facility**

**Show the following components:**

- **natural gas inlet, shut-off valve, programmable flow-controller, flow meter with pulse generator, “heat of combustion analyzer”**
- **pilot flame, flow control to various regions to maintain flame height, burner dimension, “fire-eye”**

# HRR Calibration System

## Elements

Natural Gas (daily basis)

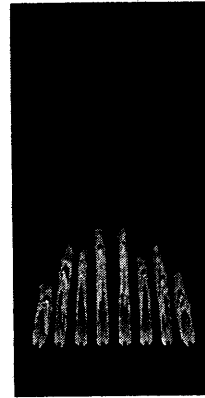
Caloric determination of Hc of natural gas

## Flow Control

- Safe (industrial control design)
- Accurate (NIST Calibrated)
- Lab View Flow Control & Measurement

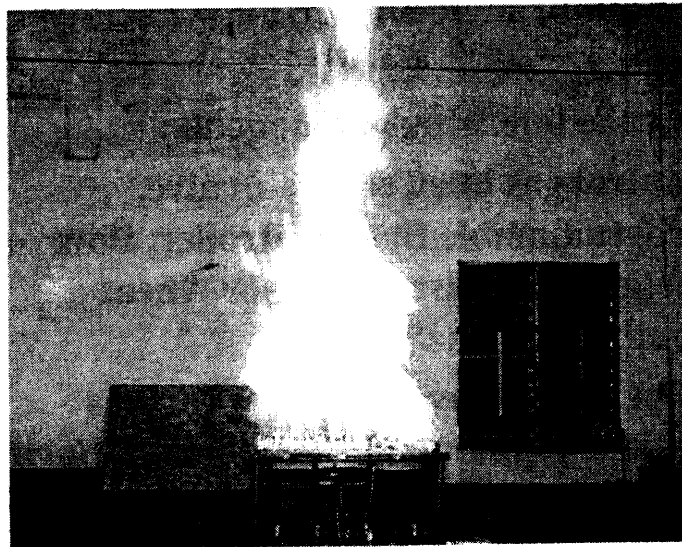
## Tube Burner

- High turndown Ratio (50 kW-6 MW)
- Design used FDS calculations

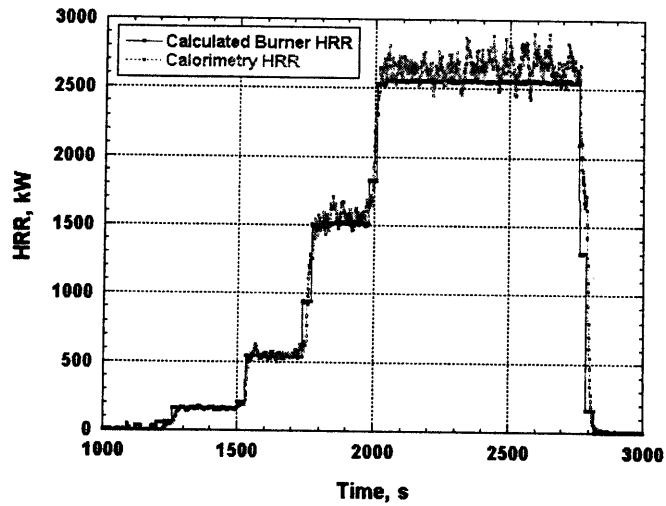


FDS Average Flame Height  
4 MW Fire in Tube Burner

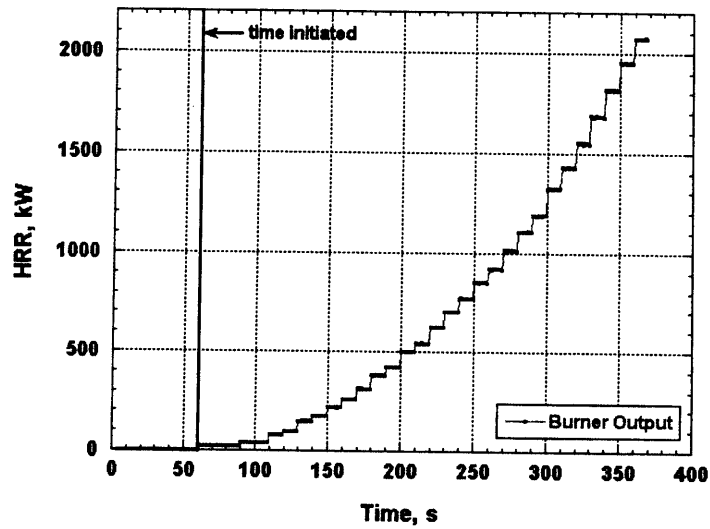
## Calibration Burner, 3 MW



### Comparison of the Burner Output Based on Flowrate to the Heat Release Rate

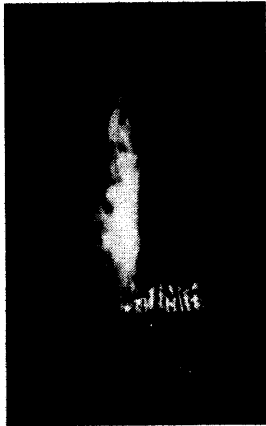


### Calibration Burner $t^2$ Burn Designed for a Peak Heat Release of 2.04 MW

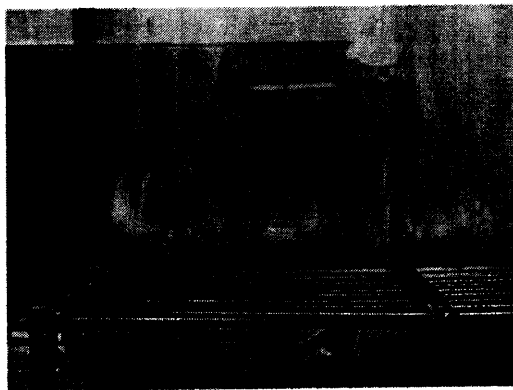
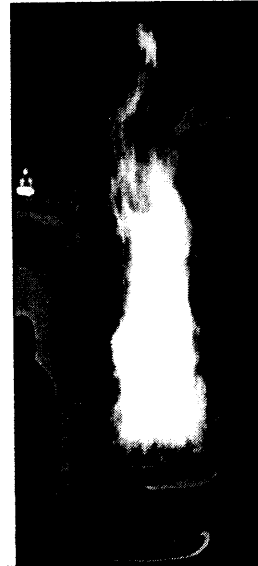


## Calibration Burner Range Test

Two of 11 tubes used to see if  
a blowoff condition could be  
attained

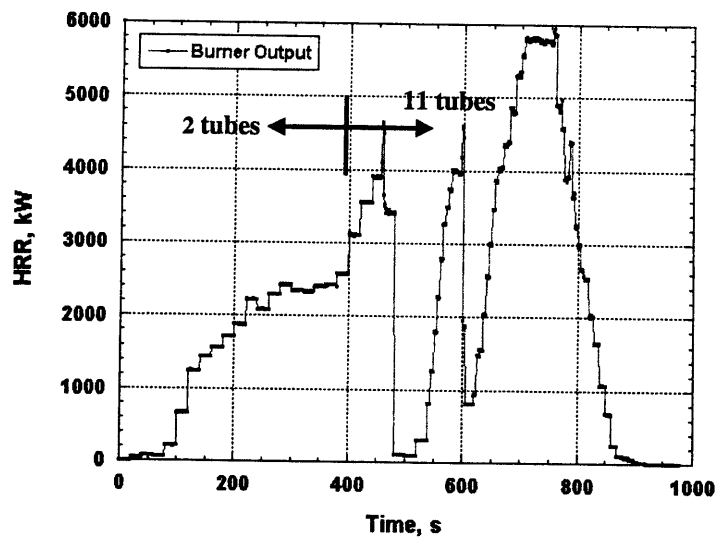


6 MW with 11 Tubes



Close-up of lower section of 1.5 MW natural  
gas flame (using 2 tubes). Note low soot level

### Calibration Burner Range Test in Large Hood

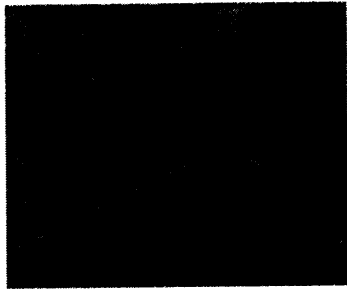


### Future Capabilities

- Soot volume fraction in upper layer
- Heat transfer measurements in upper layer
- Surface temperature
- Chemical analysis/FTIR
- Doorway Flow Measurements
- Water Spray Measurements
- ISO 17025 Testing Laboratory Competence
- Integrated research approach - model used for designing and interpreting results

**Future Large-Scale Capability: Simultaneous  
Droplet Velocity and Size**

**Fluorescing sprinkler spray,  
70 cm by 60 cm measurement  
area**



**Droplet trajectories fluoresced  
by laser sheets**

